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RESEARCH MEMORANDUM

ICE PROTECTION OF TURBOJET ENGINES BY INERTIA SEPARATION OF WATER

II - SINGLE-OFFSET-DUCT SYSTEM

By Uwe von Glahn

Flight Propulsion Research Laboratory
Cleveland, Ohio

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RESEARCH MEMORANDUM

ICE PROTECTION OF TURBOJET ENGINES BY INERTIA SEPARATION OF WATER

II - SINGLE-OFFSET-DUCT SYSTEM

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SUMMARY

The results of an aerodynamic and icing investigation of a single-offset-duct system that was designed to prevent the entrance of water and foreign particles into a turbojet engine are presented. The results show that the single-duct inlet incorporating internal water-inertia separation features had a 2 percent better ram-pressure recovery than that for the alternate duct used in the two-concentric-duct system. The single-duct ram-pressure recovery of 77 percent, however, was considerably less than the recovery attained with the main duct of the two-concentric-duct system. Good ice protection was attained with the configuration investigated.

INTRODUCTION

The design of a single-duct inlet of the internal water-inertia separation design has several advantages over the two-concentric-duct system described in reference 1 provided that a high ram-pressure recovery can be attained. The single-offset-duct design eliminates the rapid diffusion at the alternate-duct inlet and outlet, which are inherent in the main duct of the concentric-duct system. The single-offset-duct system also is independent of the main-duct-screen icing characteristics during an icing condition. Furthermore, small dust particles and even pebbles can be effectively prevented from entering the engine by proper design of the inlet. For fabrication and installation, the single offset duct is lighter and has more space available for accessories than the two-concentric-duct system. The accessory-housing nose can be more easily and better armored than direct-ram or concentric-duct-inlet systems, thereby providing more protection for the engine.

The unheated icing tolerance, which is relatively great for the two-duct system, is considerably reduced for the single-duct system because of the elimination of the main duct that serves as an ice trap for a large amount of water entering through the nacelle inlet. A greater surface area must be heated continuously and provided with water drains in order to have the system operate effectively.

In order to determine the characteristics of a single-offset-duct system, aerodynamic and preliminary icing investigations were conducted in the NACA Cleveland icing research tunnel on several one-half-scale internal water-inertia separation single-duct inlets at a tunnel velocity of approximately 260 to 280 miles per hour and simulated icing conditions at a temperature of approximately 24° F.

SYMBOLS

The following symbols are used in this report:

H total pressure with reference to test chamber, pounds per square foot

L maximum cross-sectional height of duct at any section, inches

l distance from outer duct wall to total-pressure tubes, inches

q dynamic pressure of air stream, pounds per square foot

T total temperature of free air stream, °F

V indicated airspeed, miles per hour

α angle of attack of nacelle, degrees

η ram-pressure recovery, $\left[1 - \left(\frac{H_0 - H_2}{q_0}\right)\right]$

Subscripts:

0 free stream

1 nacelle inlet

2 compressor inlet

av average

APPARATUS AND INSTRUMENTATION

All the investigations reported herein were conducted with models that were modifications of configurations A-1 and A-7 with nacelle noses N-1 and N-2 (reference 1). All inlet models were of 21-inch maximum diameter corresponding to the one-half-scale dimensions of an axial-flow engine rated at 4000-pounds static thrust at sea level utilizing an 11-stage compressor, eight cylindrical burners, and a single-stage turbine. The design inlet-velocity ratio (0.77) as determined by the minimum nacelle-inlet cross-sectional area was based on a free-stream velocity of 550 miles per hour and a maximum air flow of 19.6 pounds per second at an altitude of 40,000 feet.

The models were instrumented at the compressor-inlet section in order to obtain circumferential mass-flow variations around the model, velocity profiles, and ram-pressure recovery. A screen of circumferentially mounted wires 0.062 inch in diameter spaced 0.25 inch apart was mounted ahead of the compressor inlet. Details of the instrumentation are given in reference 1.

The first configuration, B-1 (fig. 1(a)) consisted of configuration A-1 (reference 1) with the main duct blocked and a 12-inch-diameter plate secured to the duct-splitter ring flush with the leading edge of the ring to provide a faired inner surface for the air entering the duct elbow.

Configuration B-2 differed from B-1 in that the 12-inch-diameter plate was moved farther aft in the main duct to increase the icing tolerance of the system by providing an ice trap, as shown in figure 1(b).

For configuration B-3, (fig. 1(c)), the duct-splitter ring from configuration A-7 (reference 1) was utilized and a spike-nose accessory housing was designed to provide a constant-area duct from the nose to the duct elbow. The purpose of the spike nose was to maintain good flow characteristics from the nose-inlet section through the elbow as well as to stabilize the flow in the duct at high angles of attack.

Configuration B-4 (fig. 1(d)) was a modification of configuration B-3. In this design, the spike-nose section was moved rearward 1 inch to increase the icing tolerance of the system by providing an ice trap similar to design B-2 and yet maintaining good flow characteristics. This configuration no longer maintained the constant cross-sectional area associated with configuration B-3.

For configurations B-1 to B-3, the original nacelle nose N-1 was used; however, for design B-4 the redesigned nose N-2 (reference 1) was utilized.

PROCEDURE

The investigation was conducted in the 6- by 9-foot test section of the Cleveland icing research tunnel at a tunnel velocity of approximately 280 miles per hour.

The aerodynamic investigation was made with the screen removed from the model at angles of attack of 0°, 4°, and 8° and at inlet-velocity ratios ranging from 0.2 to 0.75.

A series of preliminary icing investigations were made with the screen in place and at the design inlet-velocity ratio to determine the icing characteristics of the inlets. The icing investigations were conducted at an angle of attack of 0° and at an airspeed of 260 miles per hour. The spray equipment was the same as described in reference 1 and produced effective droplet sizes varying from 12 to 15 microns, as determined by volume maximum. The maximum duration of the icing runs was 15 minutes after which residual icing photographs were taken of the model. The temperature for the icing investigation was approximately 22° F. Additional information on the spray equipment is contained in reference 1.

RESULTS AND DISCUSSION

Aerodynamic Investigation

The aerodynamic results obtained were similar to the results of reference 1 for the condition in which the main duct was blocked off and only air entered the compressor-inlet section through the alternate duct.

<u>Ram-pressure recovery.</u> - The ram-pressure recovery η was calculated as $\left[1 - \left(\frac{H_0 - H_2}{q_0}\right)\right]$ where the total-pressure difference is the integrated average pressure differential $(H_0 - H_2)$ of all the aerodynamic rakes in the compressor section. Ram-pressure recoveries for the configurations investigated with no screens are shown in figure 2 as a function of inlet-velocity ratio. Moving the plate aft thus providing an ice trap decreased the ram-pressure recovery slightly (B-1 and B-2). Increasing the gap opening (B-3 and B-4 as

compared to B-1 and B-2) improved the ram-pressure recovery by as much as 20 percent at the design-inlet velocity ratio; this improvement, however, was accomplished at a sacrifice in water-separation characteristics. At no time did the ram-pressure recovery approach that of the direct-ram inlet A-0 with nose N-1 (reference 1) at the design inlet-velocity ratio. In general, the ram-pressure recovery for the single-duct inlets was improved by 2 percent over that obtained with the main duct blocked for the same components (A-1 and A-7) in reference 1 and reached a maximum of 0.77 at the design inlet-velocity ratio, which is considerably lower than the ram-pressure recovery for the direct-ram inlet.

Velocity distributions. - Typical radial profiles of velocity at angles of attack of 0° and approximately 8° are shown in figure 3 for the single-duct inlets. These profiles are similar to those obtained in reference 1 for the same alternate-duct configurations. A slight improvement in the velocity profile was obtained when the spike nose (B-3) was used. It was observed that the spike nose improved the flow stability. The mass-flow shifts that occurred at angles of attack over 6° with alternate duct A-7 and nacelle nose N-1 (reference 1) did not occur with B-3 up to an angle of attack of 8°.

Icing Investigation

In general, the ice formations were similar to those observed in reference 1.

Configuration B-1 (fig. 4(a)) had a very low icing tolerance. Ice formations near the rim of the flat disk, which formed one wall of the duct, were very rough and soon constricted the passage to such an extent that the air flow rapidly decreased. In less than 2 minutes of icing, the ram-pressure recovery decreased from about 68 to 20 percent. The ice trap in configuration B-2 (fig. 4(b)) provided increased icing tolerance as compared to B-1 and no appreciable ram-pressure loss was caused by icing in 10 minutes. The remainder of the duct was iced in a manner similar to configuration A-1 of reference 1.

Configuration B-3 was not investigated in an icing condition because it contained no ice trap. Configuration B-4 iced in a manner similar to design B-2, as shown in figure 4(c), and no appreciable ram-pressure loss was experienced in 15 minutes, although some screen icing occurred.

Design recommendations. - Continuous heating of the accessory-housing surface would be required for inlets that have small ice traps. In addition, the same surfaces may have to be locally heated as those in the double ducts, namely, nacelle nose and inlet surfaces and the duct elbows wherever secondary inertia separation occurs.

SUMMARY OF RESULTS

An investigation was conducted to determine the aerodynamic and icing characteristics of a single-offset-duct system. The single-duct system incorporating internal water-inertia separation features had a ram-pressure recovery approximately 2 percent greater than for the same alternate-duct configurations. At the design inlet-velocity ratio of 0.77, a maximum ram-pressure recovery of 77 percent was obtained with good ice protection. This ram-pressure recovery was considerably less than the recovery attained with the main duct of the two-concentric-duct system.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCE

1. von Glahn, Uwe: Ice Protection of Turbojet Engines by Inertia Separation of Water. I - Alternate-Duct System. NACA RM No. E8A27, 1948.

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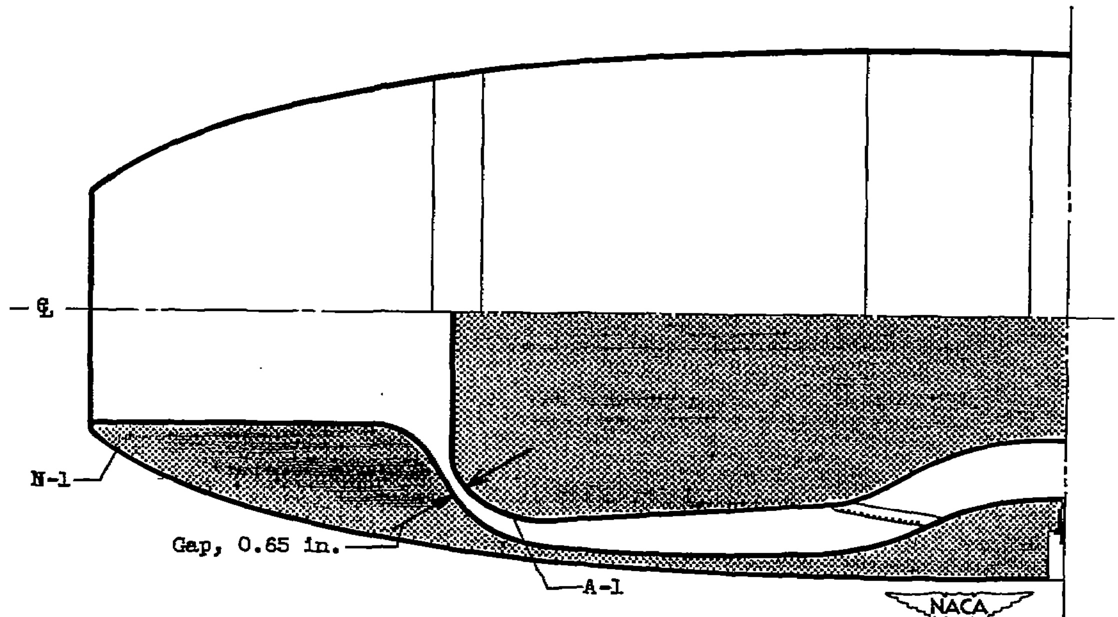
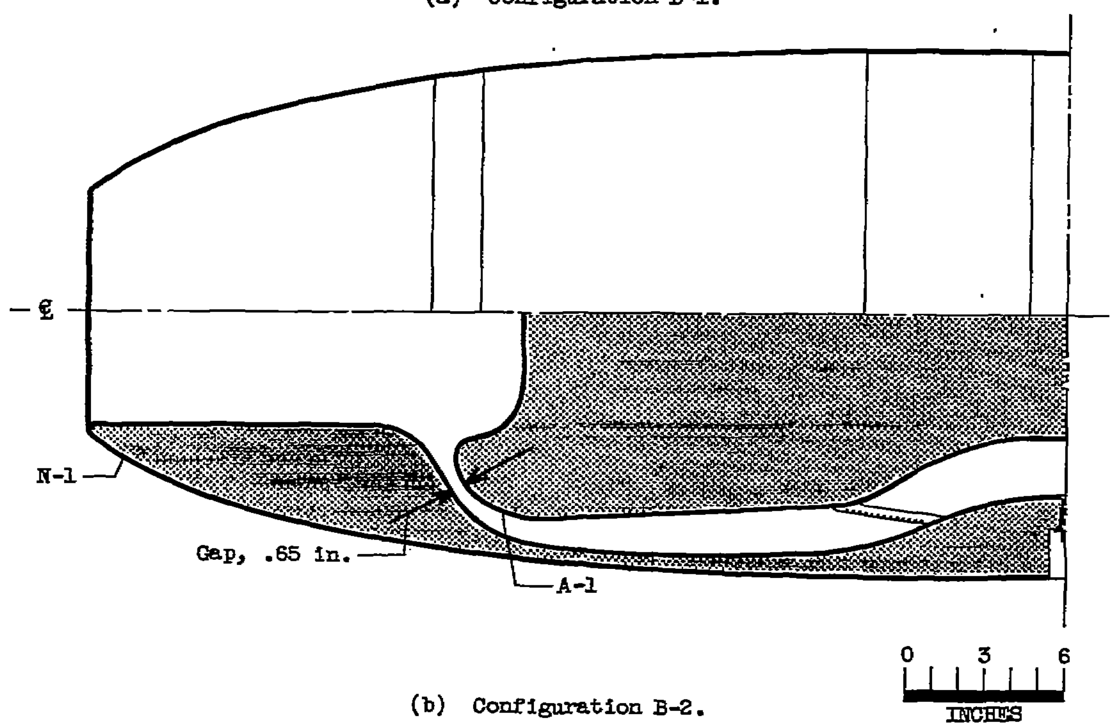
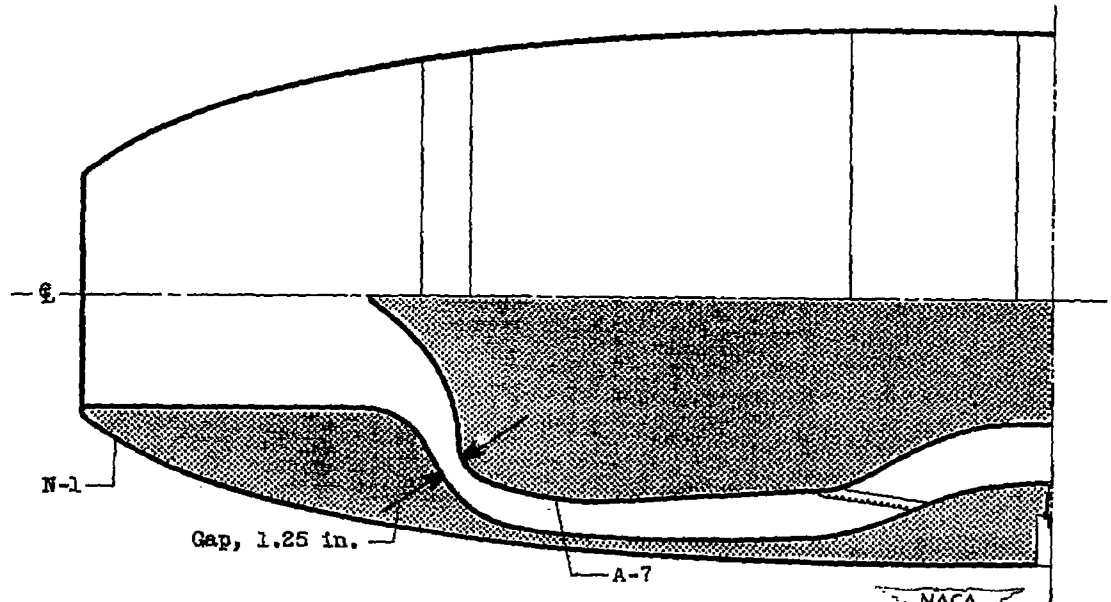


(a) Configuration B-1.

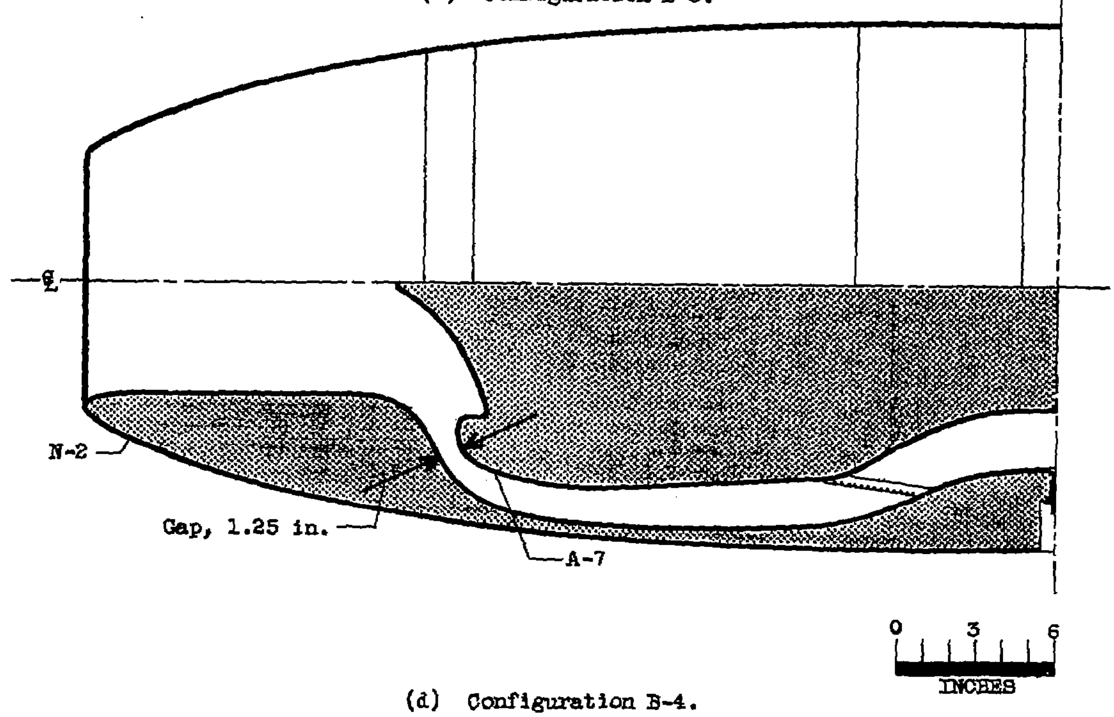


(b) Configuration B-2.

Figure 1. - Cross sections of single-duct water-inertia separation inlets.



(c) Configuration B-3.



(d) Configuration B-4.

Figure 1. - Concluded. Cross sections of single-duct water-inertia separation inlets.

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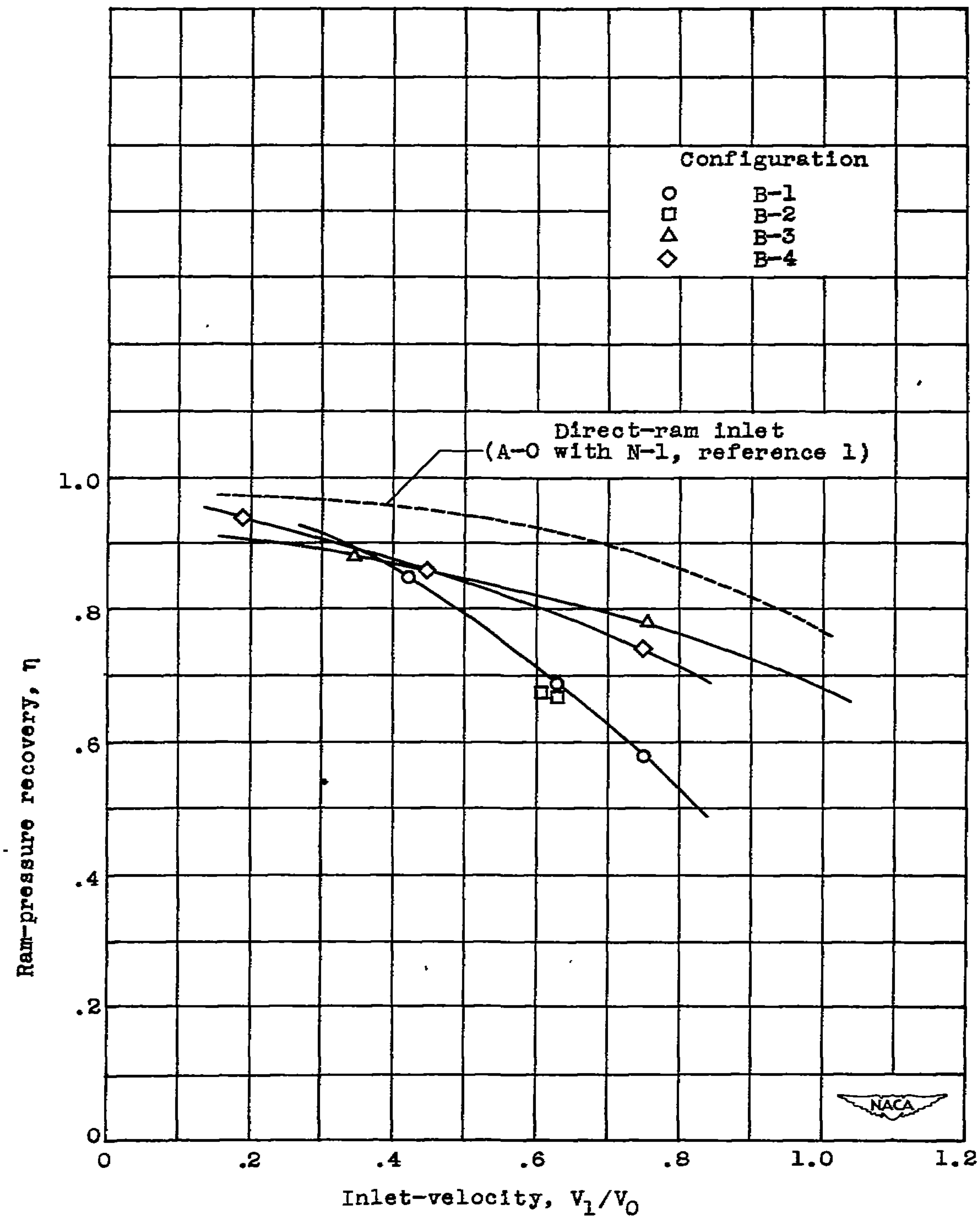
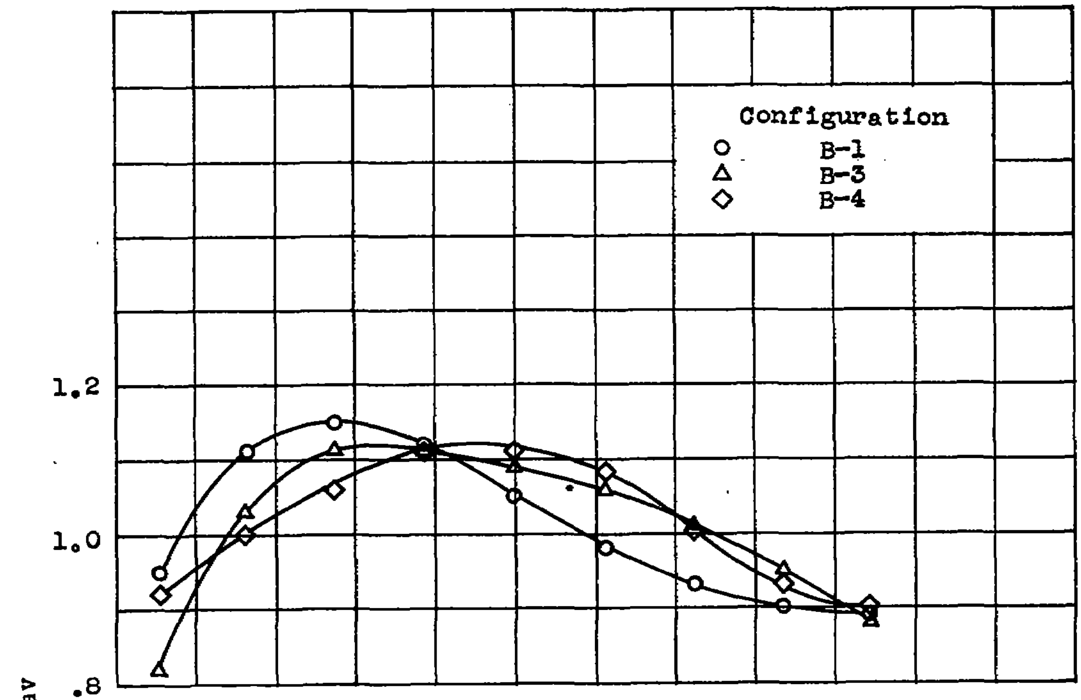
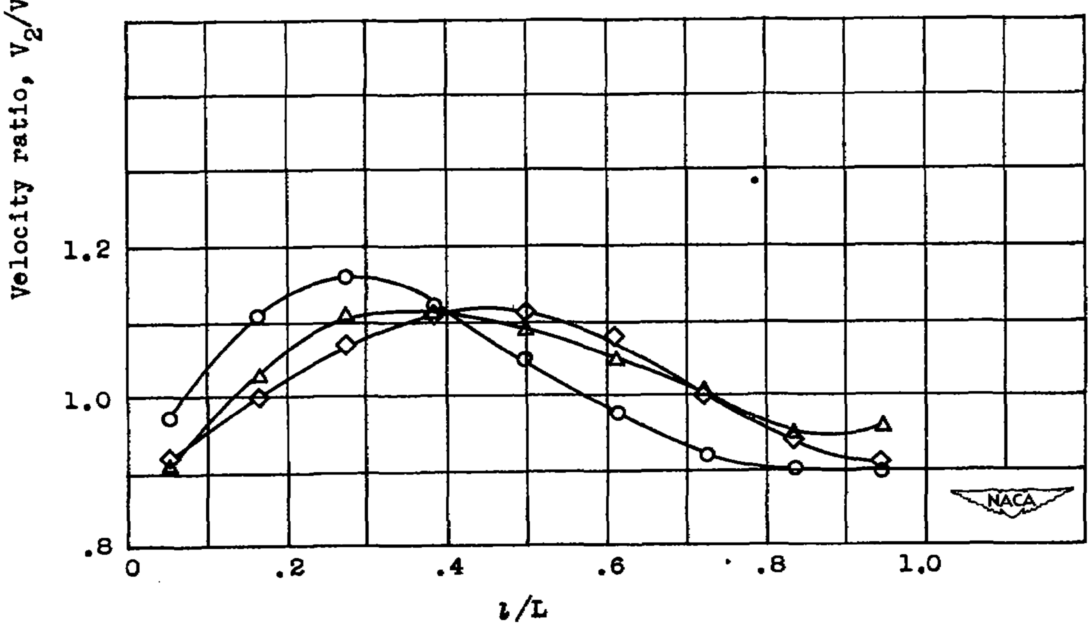


Figure 2.- Variation of ram-pressure recovery with velocity ratio. Airspeed V_0, 280 miles per hour; angle of attack α, 0°.



(a) Angle of attack, α, 0°.



(b) Angle of attack, α, approximately 8°.

Figure 3.- Typical radial profiles of velocity at compressor inlet. Airspeed V_0, 280 miles per hour; inlet-velocity ratio V_1/V_0, 0.75.

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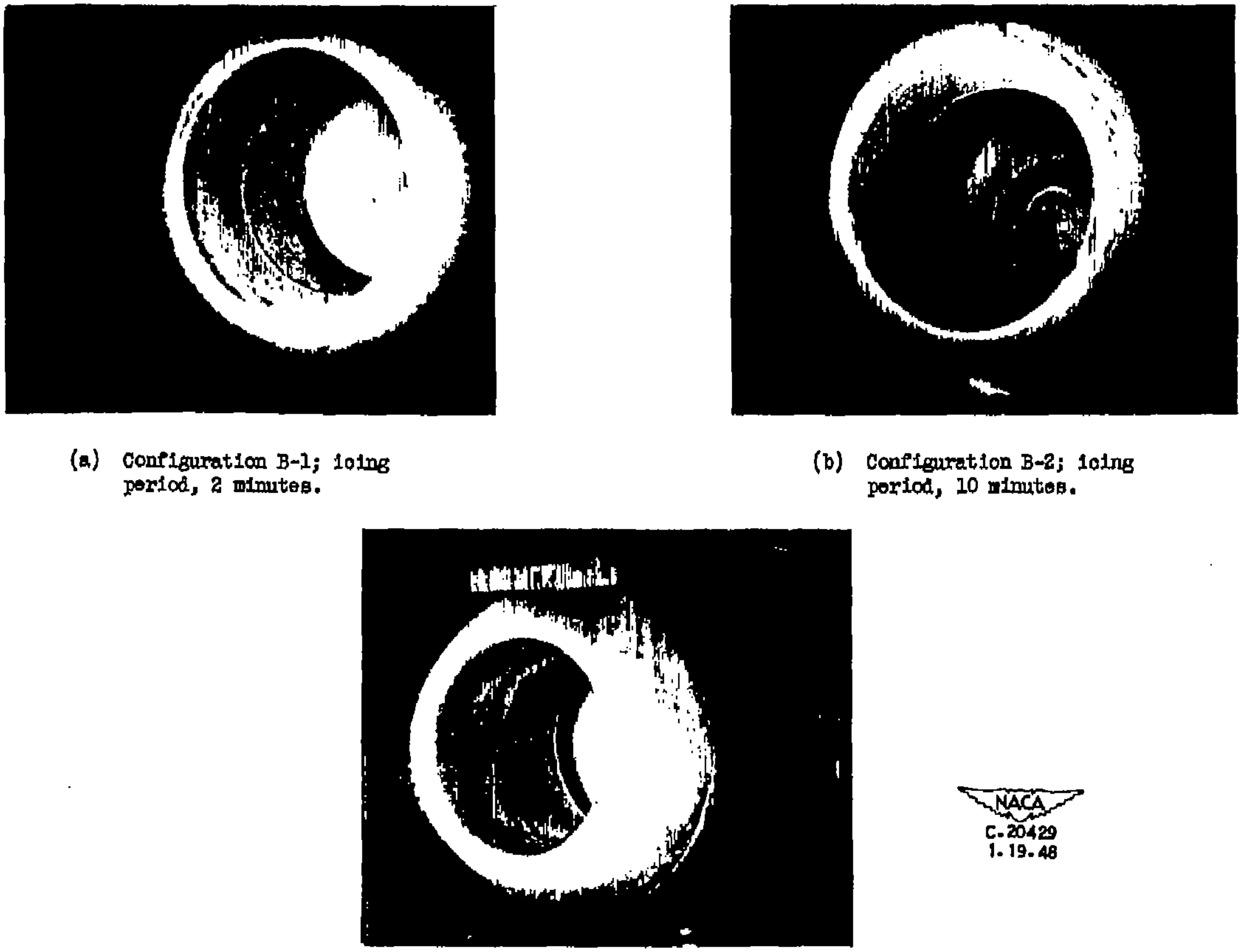

(a) Configuration B-1; icing period, 2 minutes.

(b) Configuration B-2; icing period, 10 minutes.

(c) Configuration B-4; icing period, 15 minutes.

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Figure 4. - Typical ice formations on single-duct inlets. Airspeed V_0, 280 miles per hour; temperature T, 24° F; angle of attack α, 0°.